Lunar Reconnaissance Orbiter: (Diviner)

Audience
Grades 9-10

Time Recommended
1-2 hours

AAAS STANDARDS
- 12A/H1: Exhibit traits such as curiosity, honesty, openness, and skepticism when making investigations, and value those traits in others.
- 12E/H4: Insist that the key assumptions and reasoning in any argument—whether one's own or that of others—be made explicit; analyze the arguments for flawed assumptions, flawed reasoning, or both; and be critical of the claims if any flaws in the argument are found.
- 4A/H3: Increasingly sophisticated technology is used to learn about the universe. Visual, radio, and X-ray telescopes collect information from across the entire spectrum of electromagnetic waves; computers handle data and complicated computations to interpret them; space probes send back data and materials from remote parts of the solar system; and accelerators give subatomic particles energies that simulate conditions in the stars and in the early history of the universe before stars formed.

NSES STANDARDS
Content Standard A (5-8): Abilities necessary to do scientific inquiry:

c. Use appropriate tools to gather, analyze and interpret data.

d. Develop descriptions and explanations using evidence.

e. Think critically and logically to make relationships between evidence and explanations.

Content Standard E (5-8): Science and Technology:

b. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size, and speed. Technology also provides tools for investigations, inquiry, and analysis.

MATERIALS
- One set of handouts per group, consisting of:
  - » Student Guide
  - » Four individual worksheets:
    - » Thermal Analyst worksheet
    - » Hydrologist worksheet
    - » Communications Technician worksheet
    - » Energy Technician worksheet
- Four color laminates (one corresponding to each role/worksheet:
  - » Diviner temperature map
  - » LEND neutron map
  - » Earth visibility map
  - » Sun visibility map
- Calculators
- Pens
- Whiteboard/flip chart for recording student responses

Planning a Mission to the Lunar South Pole

Learning Objectives:
- Learn about recent discoveries in lunar science.
- Deduce information from various sources of scientific data.
- Use critical thinking to compare and evaluate different datasets.
- Participate in team-based decision-making.
- Use logical arguments and supporting information to justify decisions.

Preparation:
See teacher procedure for any details.

Background Information:
The Moon's surface thermal environment is among the most extreme of any planetary body in the solar system. With no atmosphere to store heat or filter the Sun's radiation, midday temperatures on the Moon's surface can reach 127°C (hotter than boiling water) whereas at night they can fall as low as -173°C, which is almost as cold as liquid oxygen.

In addition, there are places in the lunar-polar regions where temperatures as low as -248°C have been measured– these are the coldest places observed to date within our entire solar system!

The primary reason for the extremely low temperatures measured at the lunar poles is due to the Moon's axial tilt of only 1.5°, compared to 23.5° on Earth. This means that at the lunar poles the Sun is constantly low on the horizon, thus the insides of polar impact craters receive no direct energy from the Sun. They are what have become known as **'permanently-shadowed regions.'**

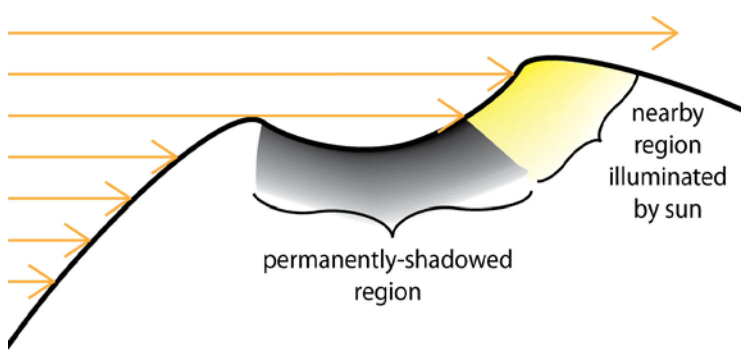

Figure 1. Diagram of a permanently-shadowed region within a crater at the lunar pole (not to scale).

TIP:
Using a bowl and a desk lamp is a simple way to demonstrate the concept of permanently-shadowed regions.

THE KELVIN TEMPERATURE SCALE:

When describing extremely cold temperatures such as those observed on the Moon, scientists use the Kelvin (K) unit of measurement. Unlike the Celsius or Fahrenheit temperature scales, there are no negative values of Kelvin. This is because 0K corresponds to “absolute zero”— the coldest possible temperature at which point an object’s molecules would cease to vibrate and therefore no longer produce any heat.

One Kelvin is equivalent in magnitude to one degree Celsius (°C). This means that intervals in the two scales are equally spaced, for example, the melting and boiling points of water, which are 273K (0°C) and 373K (100°C) respectively. This is not the case with the Fahrenheit scale (32°F and 212°F).

KEY POINTS:

- Kelvin is a unit of temperature used by scientists.
- It contains only positive values.
- 0 Kelvin—“Absolute Zero”—is the lowest temperature possible.

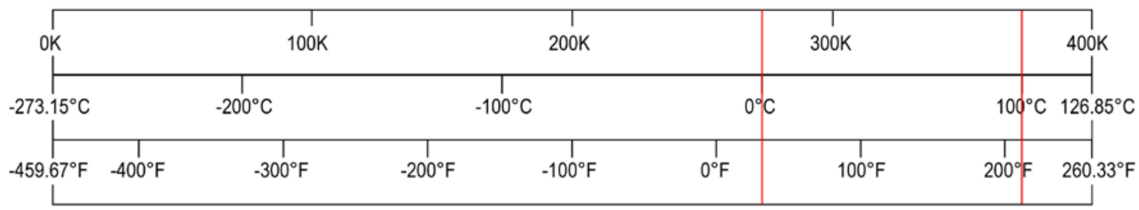

Figure 2. Temperature scales: Kelvin (top), Celsius (middle) and Fahrenheit (bottom). Red lines represent melting and boiling points of water.

The relationship between Kelvin and Celsius can be expressed as the following mathematical equation:

$$K = °C + 273$$

PERMANENTLY-SHADOWED REGIONS AND ICE:

Due to the extremely low temperatures inside permanently-shadowed regions, scientists have long theorized that these locations could act as ‘cold traps’– places where water and other compounds become frozen within the soil, accumulating over billions of years.

However it wasn’t until 2009, when the Lunar Crater Observation and Sensing Satellite (LCROSS) was deliberately crashed into the floor of Cabeus crater near the Moon’s south pole, that scientist’s theories were finally proven - the material excavated as a result of that impact was found to contain around 5% water!

It’s still too early to know for certain where the ice stored in these polar cold traps comes from or how it got there, but scientists predict that it was most likely delivered to the Moon during impacts from water-bearing comets, asteroids and meteoroids.

KEY POINTS:

- Permanently-shadowed regions on the Moon are cold enough to store water and other ices.
- Lunar ice most likely derives from comet and asteroid impacts.

FIgure 3. LCROSS

THERE ARE CURRENTLY TWO INSTRUMENTS INVOLVED IN INVESTIGATING LUNAR COLD-TRAPS:

The Diviner Lunar Radiometer:

FIgure 4. The Diviner Lunar Radiometer

The Diviner Lunar Radiometer is one of seven instruments aboard NASA's Lunar Reconnaissance Orbiter (LRO), which has been orbiting the Moon since June 2009. It is the first instrument to measure the entire range of temperatures experienced on the Moon's surface.

> **KEY POINTS:**
>
> - Diviner measures infrared and visible radiation.
> - These observations tell scientists how warm the lunar surface is and how much light it receives.

How it works:

When solar radiation hits the Moon, some of it is reflected back out to space, while some is absorbed and re-emitted as infrared radiation. Diviner measures the amount of emitted infrared and reflected visible radiation. From these measurements, scientists are able to determine the temperature of the Moon's surface along with other information such as the amount of illumination the surface receives.

The Lunar Exploration Neutron Detector:

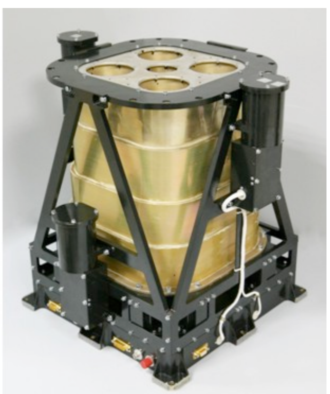

FIgure 5. The Lunar Exploration Neutron Detector (LEND)

The Lunar Exploration Neutron Detector (LEND) is another instrument aboard LRO. It measures the amount of neutrons coming off of the Moon's surface, which can be used to infer the presence of water.

> **KEY POINTS:**
>
> - Diviner measures infrared and visible radiation.
> - These observations tell scientists how warm the lunar surface is and how much light it receives.

How it works:

When cosmic rays (fast moving subatomic particles originating from outer space) bombard the surface of the Moon, they collide with atoms in the lunar soil. The collisions break down the atoms and send high-energy neutrons flying out into space.

The path of these high-energy or 'epithermal' neutrons is obstructed by the atoms of other elements present within the soil. Hydrogen, similar in size, is particularly effective at slowing down and absorbing them. The number of epithermal neutrons can therefore be used as an indicator of the concentration of hydrogen beneath the lunar surface, and as hydrogen is a key component of water, this can help determine the likelihood that water ice is present. The lower the epithermal neutron count, the higher the concentration of hydrogen and the greater chance there is of finding ice beneath the surface.

WHY BUILD A LUNAR OUTPOST?

For years, humans have envisioned one day building an outpost on the Moon. With the recent discovery of ice at the lunar poles, the prospect has become more of a reality.

We know what to expect:

The Moon is our closest neighbor. Back in the 1960s, it only took three days for the Apollo astronauts to make the trip there, and there's a good chance we can improve on this time with future technology. In addition, the communication delay between Earth and the Moon is less than 1.5 seconds, allowing for almost instantaneous audio and visual contact.

Learning about the Moon will help us understand the evolution of Earth…:
Early in its history, the Earth was impacted by a Mars-sized object, which resulted in a huge amount of debris being blown into space. Some of the debris remained in orbit around Earth, eventually coalescing to form our Moon. The Moon is the only planetary body in our solar system that shares the same origins as Earth, and therefore an ideal place to look for answers to questions such as "Where do our oceans come from?"

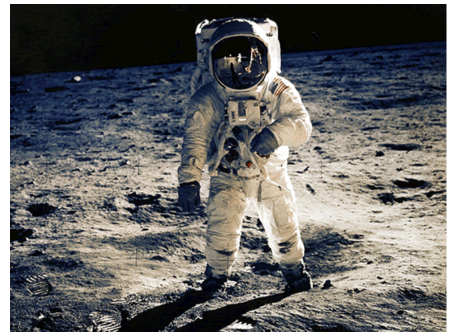

Figure 6. Astronaut Buzz Aldrin on the lunar surface during the Apollo 11 mission, 1969.

…and the Solar System:
The Moon doesn't have an atmosphere or oceans, and it's not subject to any of the geologic processes that continuously modify the Earth's surface. As a result, the Moon's surface is a near perfect record of what was going on in the early solar system, including the mysterious 'Late Heavy Bombardment' – a period around 3.9 billion years ago during which an unusually large number of impacts appear to have occurred on the Earth, Moon and other rocky planets.

It will give us good practice:
Our Moon will be the first 'off planet' destination where mankind will learn to live and work on other planets and it will be the dress rehearsal for manned missions to Mars. Building a lunar outpost will not only provide us with most of the skills and knowledge required to build a base on another planet, it could also act as a physical stepping-stone. With a gravitational field only 1/6th of Earth's, the Moon is an ideal base for launching rockets out into the solar system and beyond.

Teacher Procedure:

1. Divide students into groups; there are four roles per group, however, teachers may divide the class into smaller or larger groups depending on class size and time constraints. The roles are Thermal Analyst, Hydrologist, Communications Technician and Energy Technician.

2. Pose the question: "If humans were to build an outpost on another planet, what are the essentials that we would need?" Allow students to discuss the question within their groups have each group volunteer an agreed upon answer. Record student answers on a whiteboard or flip chart.

3. Ask students which answers they think are the most important and circle, highlight or otherwise indicate these answers in the list.

4. Review background material. Discuss with the class as a whole prior the main activity.

5. Distribute one set of handouts per group: see Supplemental Images/ Materials/ Resources section.

6. Ask one student from each group to read the student guide to the rest of the group.

PREP QUESTIONS:

7. Before starting the student guide, ask students to look at the Earth Visibility Map (located in the worksheets section). Explain that this map shows the number of Earth days each year the Earth is visible above the local horizon, which is a requirement for direct line of sight communication.

   Ask the following ➤

COMPREHENSION QUESTIONS:

Q. What do you notice about the pattern of earth visibility?
Earth visibility increases towards the top half of the map and towards the lower half there is a communication shadow.

Q. What is the reason for this pattern?
The top half of the map represents the nearside of the Moon, which is the side always facing Earth. Locations on the farside always face away from Earth and are obstructed from view by the curvature of the Moon's surface.

8. Ask students to look at the Sun Visibility Map. Explain that the map shows the number of Earth days each year that the Sun is visible in it's entirety above the local horizon.

   Ask the following ➤

COMPREHENSION QUESTIONS:

Q. The scale at the top of the map only goes up to 182.5 days (half a year). Why is that?
The sun is only up for half of the day.

Q. What color are the permanently-shadowed regions?
Gray – 0 days Sun visibility.

9. Ask the class to compare the Sun visibility map and temperature map, which shows model-calculated yearly average surface temperatures from Diviner temperature measurements.

   Ask the following ➤

COMPREHENSION QUESTIONS:

Q. How do temperatures correlate with illumination?
Temperature is strongly correlated with illumination.

Q. Is this the same on Earth? Why or why not?
Temperature is not so strongly correlated with illumination on Earth because the Earth has an atmosphere, which redistributes heat.

10. Lastly, ask students to examine the LEND neutron map. Explain that the map shows measurements of epithermal neutrons from the uppermost half meter of lunar soil.

    Ask the following ➤

COMPREHENSION QUESTIONS:

Q. What happens to the epithermal neutron count as more frozen water is present in the soil?
It decreases.

Q. Why is this?
Each molecule of frozen water is composed of two hydrogen atoms and one oxygen atom. Hydrogen slows down high-energy 'epithermal' neutrons leading to a low count of these type of neutrons.

11. If necessary, before starting the activity, review the information in the student guide.
12. Instruct students that at the end of the 30 minute exercise, each group will give a presentation to the rest of the class so that everyone can compare results.
13. Start student activity.

worksheet

STUDENT GUIDE

Planning a Mission to the Lunar South Pole

Objective

Your goal is to work as a team to determine the best location for a future lunar outpost. You will analyze scientific data and models of the Moon's south polar region to determine the potential habitability of sites, based on four environmental factors: temperature, access to water, potential for solar energy, and for communications.

Seven potential locations, each with advantages and disadvantages, have been pre-selected based on the fact they represent a range of different environments. It will be your job to evaluate which environmental factors are the most important and therefore which location is the most suitable for a lunar base.

KEY POINTS:

- There are no right or wrong answers.
- All decisions should be justified with supporting evidence.

Plan of Action

1. Form a group of four. Divide the group into the following roles and distribute worksheets and datasets accordingly, based on the role given:

Role:	**Analyzes:**	**To determine:**
Thermal Analyst	Diviner Temperature Data	Temperature
Hydrologist	LEND Neutron Data	Access to water
Communications Technician	Earth Visibility Model	Potential for communications
Energy Technician	Sun Visibility Model	Potential for solar energy

2. Complete the worksheets individually, following the instructions provided with each one.

3. When everyone has completed their worksheet, transfer the individual scores for each location onto the group worksheet.

4. Discuss your observations as a group and come to a decision about the relative importance of the four environmental factors.

5. Rank them accordingly and calculate final scores using the method described on the next page.

6. Grade the sites based on their scores.

7. Prepare a brief, 5 minute presentation for the rest of the class. You will need to cover the following points:

   a. The location that you deem most suitable for a lunar base;
   b. The grade you gave each of the datasets and why;
   c. If you ruled out any sites and why;
   d. The drawbacks of your chosen location, and how these might be overcome;
   e. What additional data/ information would have been helpful in coming to a decision.

How to Weigh Factors

If you decide that each of the four environmental factors is equally important, the final score for each location can be determined by the following equation:

$$X = T + W + I + C$$

Where: X = final score, T = score for temperature, W = score for water supply, I = score for illumination, and C = score for communication.

This equation is only valid if you deem that all factors are equally important. If you decide that some factors are more important than others, you should adjust the above equation by multiplying each score by a fraction.

For example, if you decide that temperature is the most important factor, communication is the least important, and water and illumination are equally important, the following weighting might therefore apply:

Factor	**Weight**
Temperature	0.5
Water	0.2
Illumination	0.2
Communication	0.1
Total	**1**

*Note: the sum of all the weights must equal 1.

The formula would now read: $x = (0.5)T + (0.2)W + (0.2)I + (0.1)C$

worksheet

GROUP WORKSHEET

Names ____

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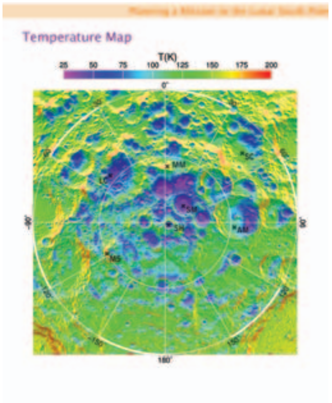
Site	Temperature Score	Temperature Weight	Temperature Weighted Score	Water Score	Water Weight	Water Weighted Score	Illumination Score	Illumination Weight	Illumination Weighted Score	Communication Score	Communication Weight	Communication Weighted Score	Total Score	Rank
Amundsen Crater														
LCROSS Impact Site														
Malapert Mountain														
M5														
Scott Crater														
Shackleton Crater														
Shoemaker Crater														

THERMAL ANALYST WORKSHEET

Planning a Mission to the Lunar South Pole



TEMPERATURE MAP

AM	Amundsen Crater
LC	LCROSS impact site
MM	Malapert Mountain
M5	M5
SC	Scott Crater
SH	Shackleton Crater
SM	Shoemaker Crater

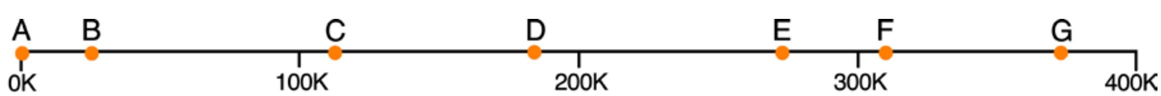
Table 1. Location Key

This map is a projection of the lunar south polar region. The center of the map corresponds to the lunar south pole, the inner circle corresponds to -85° latitude and the outer circle corresponds to -80° latitude. The map shows the model-calculated yearly average surface temperatures for the lunar south polar region. The temperatures were calculated using data from the Diviner Lunar Radiometer.

Keeping Warm on the Moon

With modern technology, we are able to substantially regulate our thermal environment. Spacesuits have been designed to withstand temperatures much lower than those on Earth, and a well-insulated, underground shelter could make even the harshest climates livable. However, extremely low temperatures can pose a risk to mechanical equipment.

Here are some key temperatures in the Kelvin scale (remember: K = °C + 273):



A (0K) = Absolute Zero
B (25K) = Coldest temperature measured on the Moon (Hermite Crater, North Pole)
C (113K) = Coldest temperature spacesuits are capable of withstanding
D (184K) = Coldest temperature measured on Earth (Antarctica)
E (273K) = Melting point of water on Earth
F (310K) = Average human body temperature
G (373K) = Boiling point of water on Earth

Worksheet Instructions

1. Measure and record the temperature at each of the seven locations.
2. Using the information on the group worksheet, and what you learned at the beginning of the lesson, decide:
   a. How you are going to order the sites in terms of suitability and;
   b. If there are any conditions the sites have to meet in order to be considered.
3. Eliminate sites which do not meet any conditions you deem essential.
4. Grade the remaining sites in order from most to least favorable, with seven points given to the most favorable, six to the next most favorable, etc. until each of the sites has a given score. If two or more sites are tied, give them each the same score.
5. Answer the questions.

worksheet

Names ____

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Site	Temperature (K)	Score
Amundsen Crater		
LCROSS Impact Site		
Malapert Mountain		
M5		
Scott Crater		
Shackleton Crater		
Shoemaker Crater		

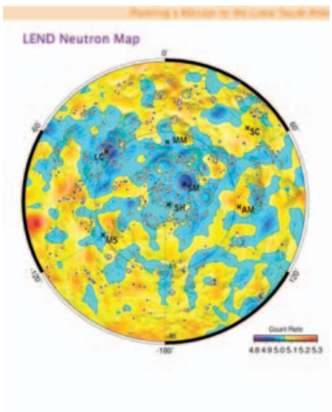
1. Explain your reasoning behind scoring the sites in the way that you have.

2. Based on your criteria, are any of the locations unsuitable? If so, why?

3. Describe how you think the Diviner data should be weighted in relation to the three other datasets and why.

HYDROLOGIST WORKSHEET

Planning a Mission to the Lunar South Pole



LEND NEUTRON MAP

AM	Amundsen Crater
LC	LCROSS impact site
MM	Malapert Mountain
M5	M5
SC	Scott Crater
SH	Shackleton Crater
SM	Shoemaker Crater

Table 2. Location Key

This map is a projection of the lunar south polar region. The center of the map corresponds to the lunar south pole, the inner circle corresponds to -85° latitude and the outer circle corresponds to -80° latitude. The “count rate” located on the key is the number of epithermal (high energy) neutrons emitted from the uppermost 0.5m of lunar soil, as measured by the Lunar Exploration Neutron Detector. Locations outlined in black indicate permanently-shadowed regions.

Water on the Moon

The human body needs water to stay alive, without it we would only survive for a few days. We also need it for growing food, cooking and bathing. It would be prohibitively expensive to transport all the water required from Earth, so it is imperative that a future lunar outpost has access to a clean water supply.

Worksheet Instructions

1. Measure and record the count rate at each of the seven locations (remember that the presence of water would result in a low count rate).

2. Using the information above, and what you learned at the beginning of the lesson, decide:

   a. How you are going to order the sites in terms of suitability and;
   b. If there are any conditions that the sites have to meet in order to be considered.

3. Eliminate sites which do not meet any conditions you deem essential.

4. Grade the remaining sites in order from most to least favorable, with seven points given to the most favorable, six to the next most favorable, etc. until each of the sites has a score. If two or more sites are tied, give them each the same score.

5. Answer the questions.

worksheet

Names ____

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Site	Neutron Count	Score
Amundsen Crater		
LCROSS Impact Site		
Malapert Mountain		
M5		
Scott Crater		
Shackleton Crater		
Shoemaker Crater		

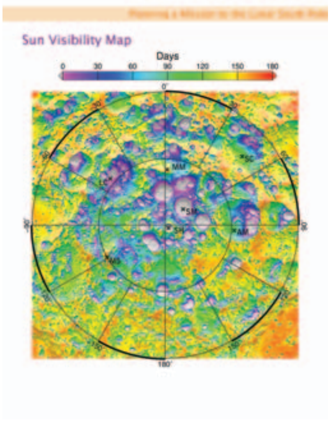
1. Explain your reasoning behind scoring the sites in the way that you have.

2. Based on your criteria, are any of the locations unsuitable? If so, why?

3. Describe how you think the LEND data should be weighted in relation to the three other datasets and why.

ENERGY TECHNICIAN WORKSHEET

Planning a Mission to the Lunar South Pole



SUN VISIBILITY MAP

AM	Amundsen Crater
LC	LCROSS impact site
MM	Malapert Mountain
M5	M5
SC	Scott Crater
SH	Shackleton Crater
SM	Shoemaker Crater

Table 3. Location Key

This map is a projection of the lunar south polar region. The center of the map corresponds to the lunar south pole, the inner circle corresponds to -85° latitude, and the outer circle corresponds to -80° latitude. The map shows the number of Earth days each year the Sun is visible in its entirety above the local horizon.

Generating Power on the Moon

Everything that runs on electricity requires a power supply; this includes lighting, vehicles, communications equipment, air pressurization units (machinery used to create a breathable atmosphere inside a structure), and hydroponic equipment (used for growing crops under artificial conditions). Thus, solar energy is the most viable power source for a lunar outpost.

Worksheet Instructions

1. Measure and record the number of days of Sun visibility at each of the seven locations.

2. Using the information above, and what you learned at the beginning of the lesson, decide:

   a. How you are going to order the sites in terms of suitability and;
   b. If there are any conditions that the sites have to meet in order to be considered.

3. Eliminate sites which do not meet any conditions you deem essential.

4. Grade the remaining sites in order from most to least favorable, with seven points given to the most favorable, six to the next most favorable, etc. until each of the sites has a score. If two or more sites are tied, give them each the same score.

5. Answer the questions.

worksheet

Names ____

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Site	Sun Visibility (days/yr)	Score
Amundsen Crater		
LCROSS Impact Site		
Malapert Mountain		
M5		
Scott Crater		
Shackleton Crater		
Shoemaker Crater		

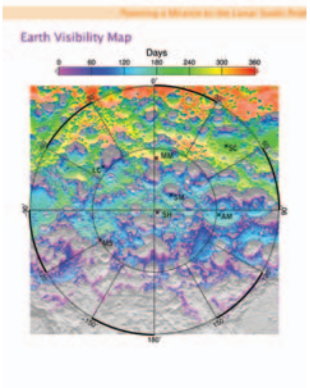
1. Explain your reasoning behind scoring the sites in the way that you have.

2. Based on your criteria, are any of the locations unsuitable? If so, why?

3. Describe how you think the Sun visibility model should be weighted in relation to the three other datasets and why.

COMMUNICATIONS TECHNICIAN WORKSHEET

Planning a Mission to the Lunar South Pole



EARTH VISIBILITY MAP

AM	Amundsen Crater
LC	LCROSS impact site
MM	Malapert Mountain
M5	M5
SC	Scott Crater
SH	Shackleton Crater
SM	Shoemaker Crater

Table 4. Location Key

This map is a projection of the lunar south polar region. The center of the map corresponds to the lunar south pole, the inner circle corresponds to -85° latitude, and the outer circle corresponds to -80° latitude. The map shows the number of Earth days each year the Earth is visible above the local horizon, which is a requirement for line-of-sight communication.

Communicating from the Moon

In order for a lunar outpost to coordinate back and forth transportation of goods and people, and to be able to request help or supplies in the case of an emergency, it would need a means of communicating with Earth. The simplest way to do this – "line-of-sight" communication – requires an unobstructed path between a radio transmitter on the Moon and a receiver on Earth.

Worksheet Instructions

1. Measure and record the number of days of earth visibility at each of the seven locations.

2. Using the information above, and what you learned at the beginning of the lesson, decide:

    a. How you are going to order the sites in terms of suitability, and
    b. If there are any conditions that the sites have to meet in order to be considered.

3. Eliminate sites that do not meet any conditions that you deem essential.

4. Score the remaining sites in order from most to least favorable, with seven points given to the most favorable, six to the next most favorable and so on until each of the sites has a score. If two or more sites are tied, give them each the same score.

5. Answer the questions.

worksheet

Names ____

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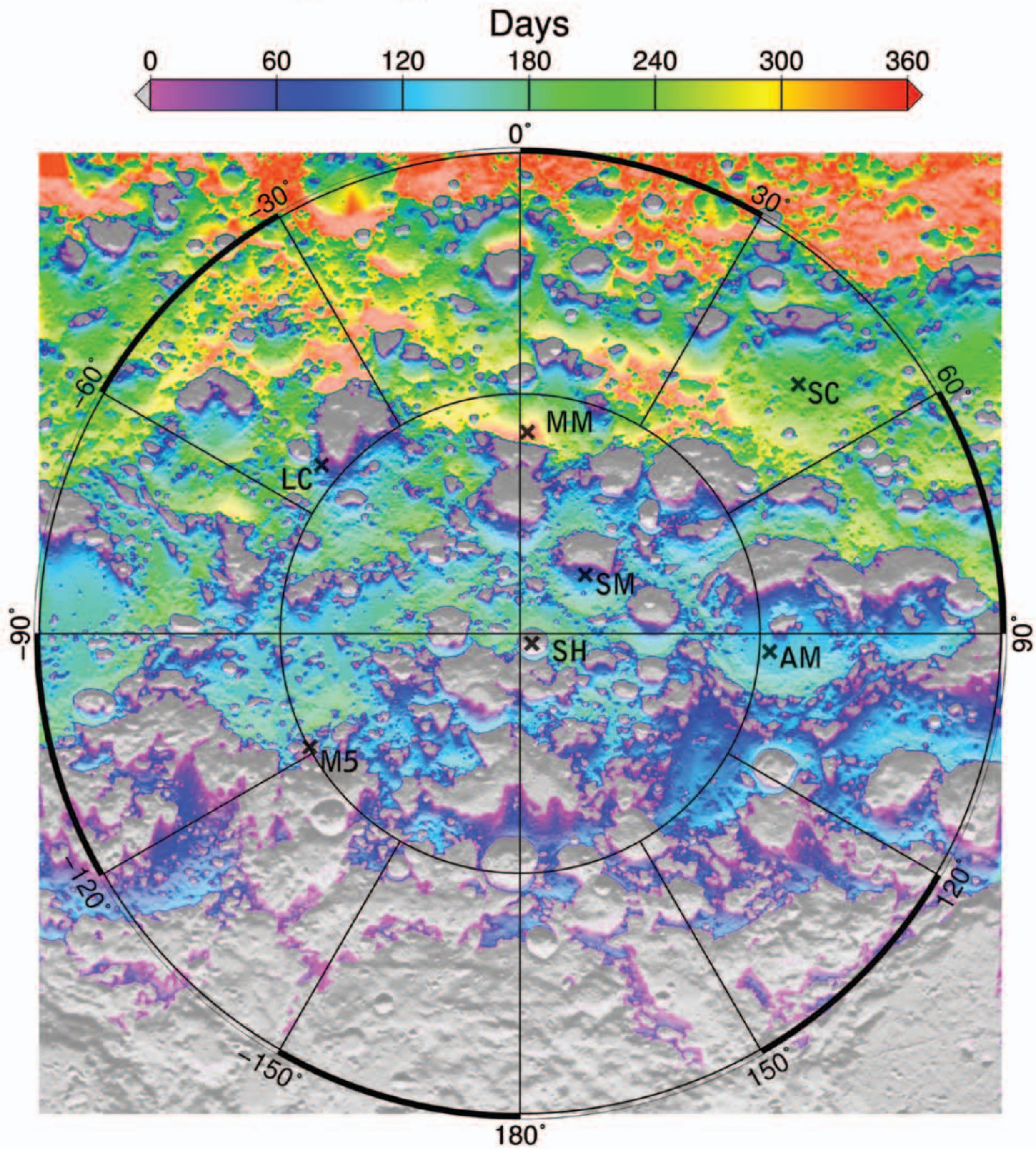
Site	Earth Visibility (days/yr)t	Score
Amundsen Crater		
LCROSS Impact Site		
Malapert Mountain		
M5		
Scott Crater		
Shackleton Crater		
Shoemaker Crater		

1. Explain your reasoning behind scoring the sites in the way that you have.

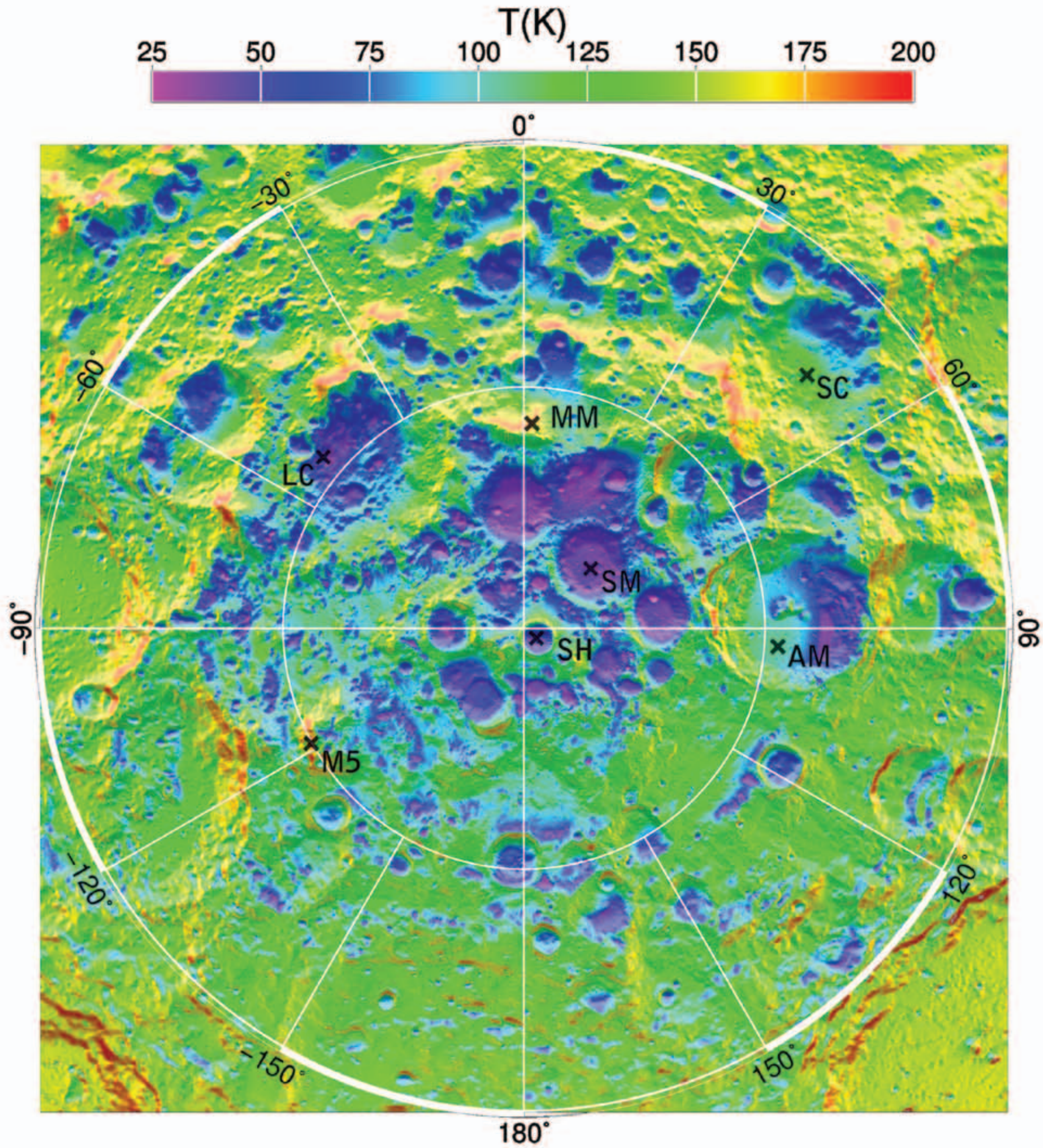
2. Based on your criteria, are any of the locations unsuitable? If so, why?

3. Describe how you think the Earth visibility model should be weighted in relation to the three other datasets and why.

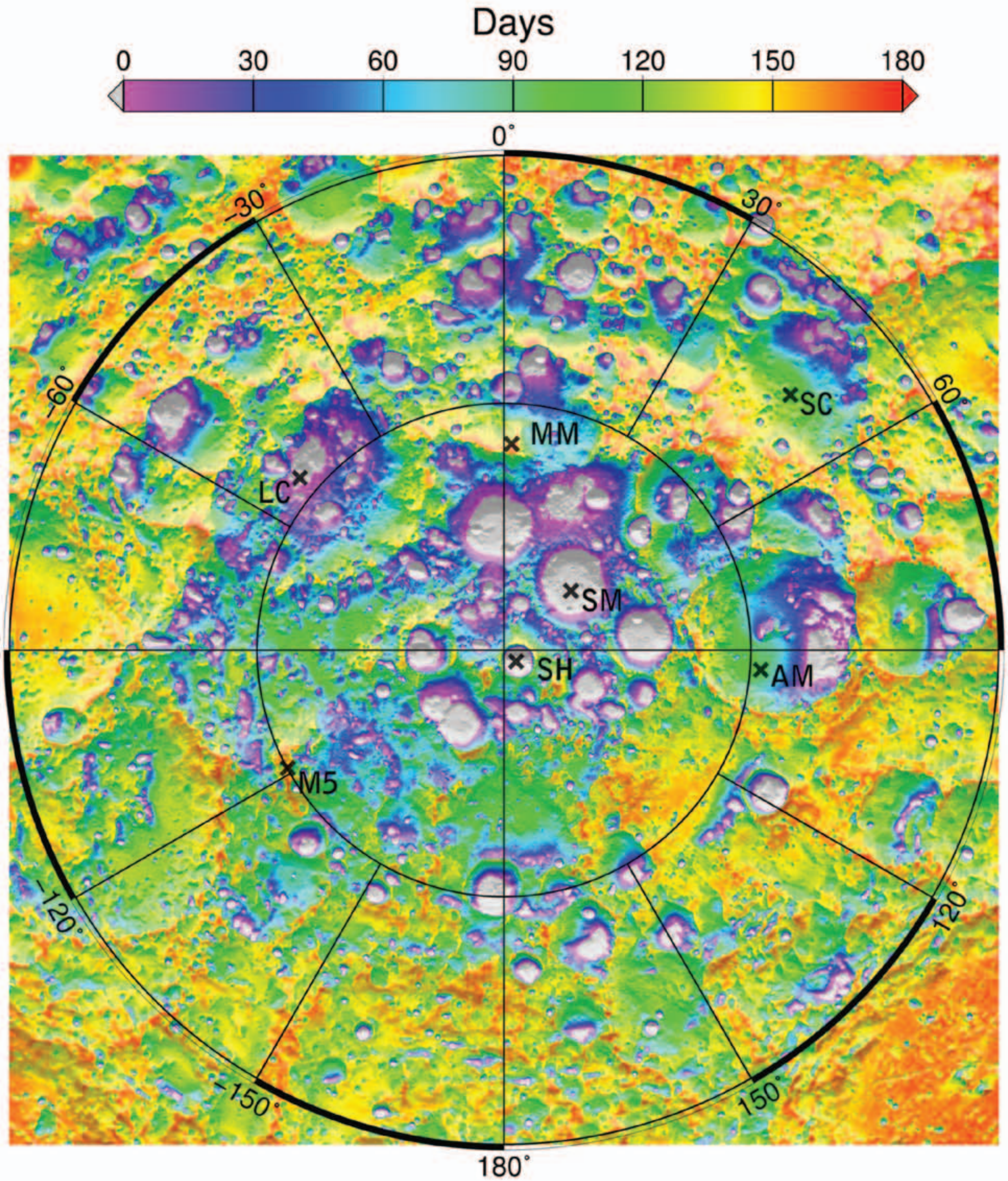
Earth Visibility Map



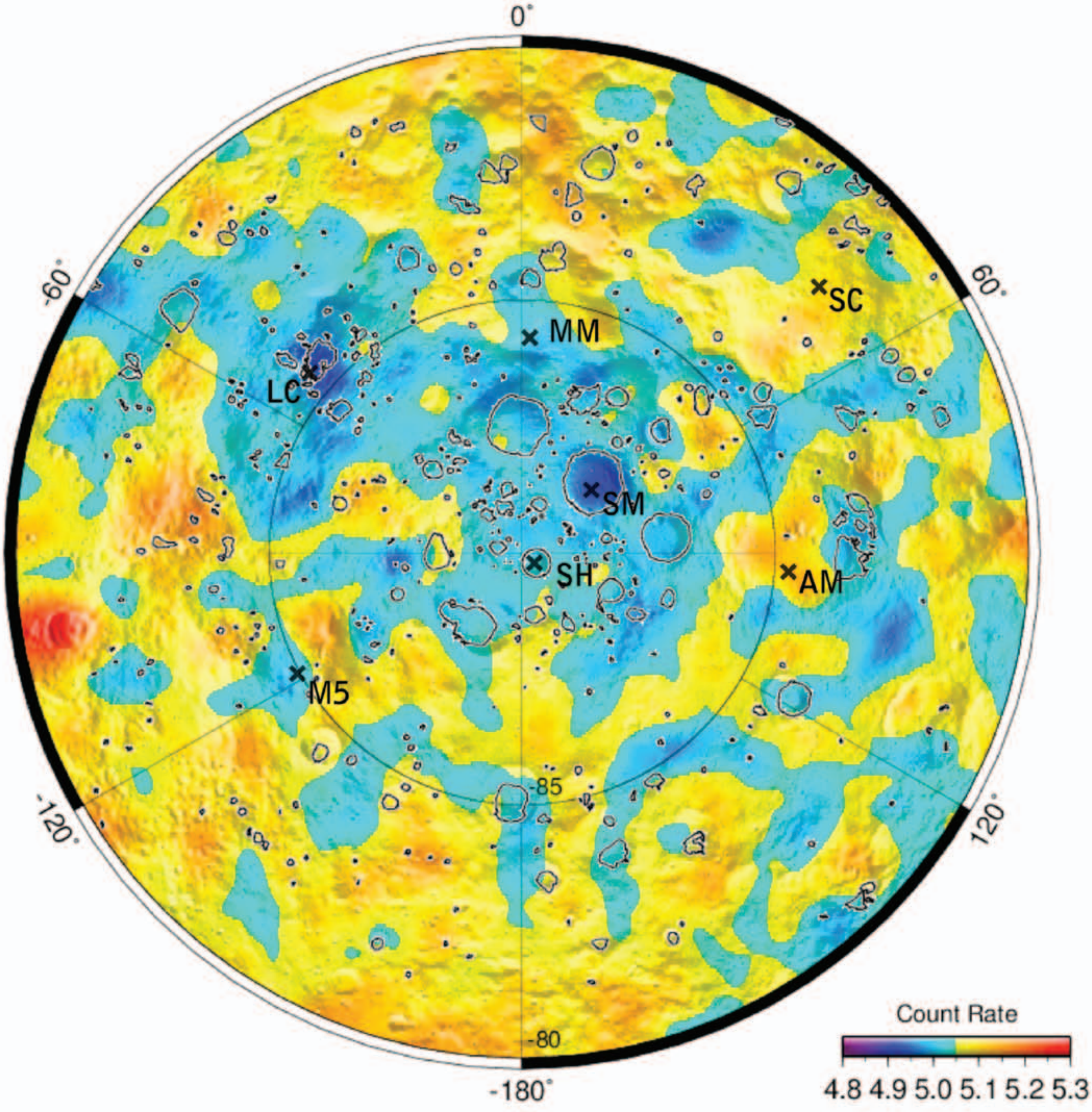
Temperature Map



Sun Visibility Map



LEND Neutron Map



TEACHER PROCEDURES

Assessment:

Use the chart below and the answer sheet on the next page to record student levels of achievement for each of the tasks in the group activity. The chart uses a scale of 5-1, with 5 representing the highest level of achievement and 1 representing the lowest. Score students for each task, and total up the scores for the entire activity. The corresponding letter grades are as follows:

A: 60 and above
B: 45-59
C: 30-44
D: 15-29
F: Below 15

Student Product	Indicator of Achievement	5	4	3	2	1
Individual Worksheets						
Table	I. Table is complete					
	II. Readings are accurate					
	III. Student has ranked locations in a logical order					
Questions	I. All questions have been answered					
	II. Student uses complete sentences					
	III. Student provides detailed explanations to back up their decisions					
	IV. Student uses information provided in this activity to justify their decisions					
	V. Student draws on outside information to justify their decisions					
Group Worksheets	I. Table is complete.					
	II. Group has weighted factors correctly - weighting reflects relative importance as described in presentation, calculations are free of errors					
Group Presentations	I. Student participates in presentation					
	II. Group provides detailed explanations for its decisions					
	III. Group uses information provided in the background to justify its decisions					
	IV. Group draws on outside information to justify its decisions					
	V. Group uses logical arguments					

Teacher Answer Sheet:

Site	Thermal Analyst Temperature (+/-10K)	Hydrologist Neutron Count (+/-0.05)	Communications Tech. Earth Visibility (+/-20 days)	Energy Technician Sun Visibility (+/-10 days)
AM	100K	5.1	140	100
LC	35K	4.95	70	0
MM	175K	5.02	320	150
M5	180K	5.03	0	170
SC	125K	5.1	210	100
SH	40K	5.02	0	0
SM	40K	4.95	70	0
Question 1	• Scores locations from high to low temperature. • Recognizes that even warmest locations are colder than the coldest temperatures measured on Earth. • Acknowledges limitations of spacesuits and equipment.	• Scores locations from low to high neutron count. • Recognizes water content (hydrogen) is inversely correlated with neutron count. • Acknowledges limitations of transporting water from Earth.	• Scores locations from high to low earth visibility. • Recognizes potential for communication in locations with more days of earth visibility per year.	• Scores locations from high to low Sun visibility. • Recognizes increased potential for solar power in locations with more days of Sun visibility per year.
Question 2	• Eliminates sites with temperatures lower than 113K (spacesuit temperature).	• Takes into account surrounding regions of sites with high neutron count.	• Takes into account surrounding regions of sites with low earth visibility.	• Takes into account surrounding regions of sites with low Sun visibility.
Question 3	• Acknowledges that warmer sites pose less risk to humans and machines. • Considers potential to regulate thermal environments.	• Acknowledges the advantages of a local water supply. • Recognizes water supply doesn't have to be onsite. • Considers potential to recycle water.	• Acknowledges benefits of continuous line of communication with Earth. • Recognizes communications facility doesn't have to be onsite. • Suggests alternatives (satellites, relays).	• Acknowledges importance of exploitable energy resource. • Recognizes power supply doesn't have to be onsite. • Suggests alternatives (nuclear, geothermal, biomass).

*This is not a definitive list of answers. Students should be given credit for demonstrating an understanding of the background material and for using logical reasoning to explain their decisions. For example, in Q2 of the thermal analyst worksheet, students might argue that spacesuit capability is likely to improve in the future and therefore choose to include locations colder than 113K.

SUPPLEMENTAL IMAGES/ MATERIALS/ RESOURCES:

Teacher Glossary

Absolute Zero: the lowest temperature possible, corresponding to 0 Kelvin. This is a theoretical temperature, which could only be achieved in the complete absence of molecular motion.

Cold-trap: a location with a low enough temperature to instantly freeze water and other molecules, preventing them from being able to escape.

Epithermal neutron: a neutron with a relatively high kinetic energy.

Late Heavy Bombardment: a period of time early in the solar system's history during which the inner "rocky" planets experienced a higher than usual flux of impacts.

Line-of-sight: the type of propagation characteristic of high-frequency radio, which requires that there is an unobstructed path between a transmitting antenna and a receiving antenna.

Permanently-shadowed region: a region within the lunar polar regions, such as a crater-floor, which because of its low elevation never receives any sunlight.

Teacher References

NASA's Lunar Reconnaissance Orbiter website:
http://lunar.gsfc.nasa.gov

Diviner Lunar Radiometer website:
http://diviner.ucla.edu

Lunar Exploration Neutron Detector website:
http://ps.iki.rssi.ru/lend_en.htm

Lunar CRaTER Observation and Sensing Satellite website:
http://lcross.arc.nasa.gov

Information about permanently-shadowed regions and ice:
http://www.messenger-education.org/library/pdf/ice_shadows.pdf

The arguments for building a lunar outpost:
http://www.nasa.gov/centers/goddard/news/series/moon/why_go_back.html

Class discussion: Do humans have the right to colonize other planets?
http://school.discoveryeducation.com/lessonplans/programs/discovermagazine-solarsystem/index.html